is molten; otherwise, the joint must be heated again at some point in the future to remove the excess solder.

Consider Joint Section 1, which is the copper tube with the ridge of solder. It is apparent that this ridge was not removed by a plumber after the joint was separated, which is not consistent with a plumber that is preparing a joint for future use. It is also apparent that this ridge of solder was not molten during the separation of the joint, and a plumber would typically supply sufficient heat to melt the excess solder to make it easy to remove. With respect to Joint Section 3, which is the copper tube that was joined to the brass compression fitting, there was a considerable amount of excess solder found on the copper tube, indicating that the solder from the original joint was not removed after the joint was separated. Also, it would not have been practical to de-solder this joint since unthreading the compression fitting could have easily separated it.

Therefore, the following findings are inconsistent with common industry practice when using a torch to separate the soldered joints:

1. The ridge of solder on the copper tube that did not melt during or after the separation of the joint.
2. The considerable amount of excess solder present on the copper tubing.
3. The separation of a soldered joint that could have readily been removed by unthreading a compression fitting.

Now consider the possibility that heat from the house fire resulted in the separation of the soldered joints. This possibility leaves the following questions unanswered:

1. Why did the ridge of solder on Joint Section 1 not melt?
2. Why did only two of the soldered joints become separated?
3. Why was most of the solder residue present on the copper tubes and not the brass fittings?
4. What was the force that separated the joints once the solder melted?

The first three questions can be answered by considering the metallurgy of the copper/solder/brass joint. This joint consists of copper and brass bonded by a thin layer of solder. The solder in this case was predominantly a tin/copper alloy. Since copper has limited solid solubility in tin, the microstructure of this alloy consists of two distinct phases: η (50:50 copper:tin) and tin, as indicated by the copper-tin alloy phase diagram in Figure 32. As previously shown, the brass in both fittings contained lead as a distinct, pure lead phase. Therefore, at the brass/solder interface, essentially pure tin is in intimate contact with pure lead.

The lead-tin alloy phase diagram shown in Figure 33 shows the consequences of this metallurgical coupling. As shown from this diagram, an alloy of lead and tin has a lower melting point than either of the pure metals. This diagram also shows that if a piece of pure tin is placed in intimate contact with a piece of pure lead and the temperature of this couple is increased, a layer of liquid metal will with a composition of 74% tin, 26% lead will form at 183 °C (361 °F). The same is true at the solder/brass interface on a microscopic level. Everywhere lead from the brass is in intimate contact with the tin phase in the solder, a film of liquid metal will form when the temperature is 361 °F or higher. Therefore, the region of solder in contact with the brass surface has an effective melting point that is 57 °F to 79 °F lower than the bulk solder alloy (418 °F - 440 °F).

This effect is shown schematically in Figure 34, and it can be used to answer the first three of the four questions presented above. First, because the solder only melts at the brass/solder interface, the joint can be separated without melting the most of the solder. Therefore, Joint Sections 1 and 2 can be separated without melting the solder ridge around the copper tube. Second, since the brass/solder interface melts at a lower temperature, the brass/copper joints will separate before the copper/copper joints. Third, since the solder only melts at the brass/solder interface, the majority of the solder is left on the copper tube.

Finally, in order to answer the fourth question, we must consider the pressure inside the water pipes during the fire. Because a drain was not installed in the sink, Mr. Kemp indicated that he would not have bled air from the water lines going to the sink. Thus, at the beginning of the fire the water lines under the sink would have been pressurized because the water was turned on but

filled with air rather than water. The ignition of portions of the wood of the kitchen sink cabinet nearby indicates that temperatures in the region of the disconnected water pipe were above 361 °F, which is sufficient to melt the solder at the brass interface as indicated above. The joints would have come apart from internal pressurization of the pipes or mechanical loads placed on the joints as components moved during the fire.

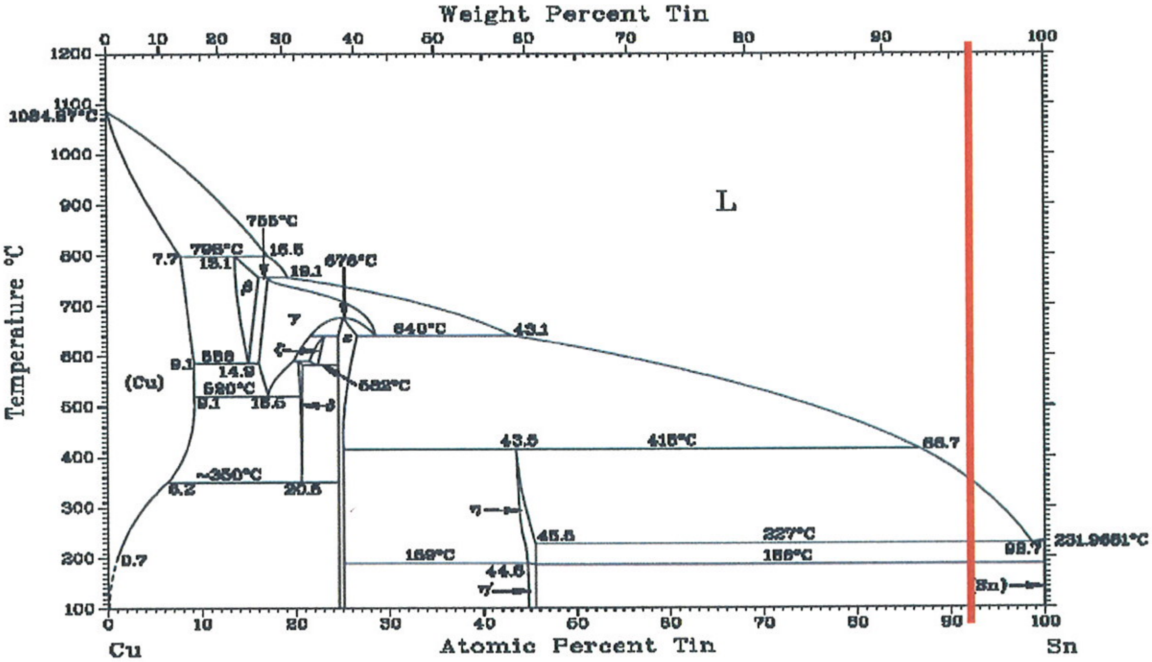

Figure 32. Copper-Tin alloy phase diagram. The red line indicates the approximate composition of the "100% Watersafe" brand solder used by Mr. Kemp.

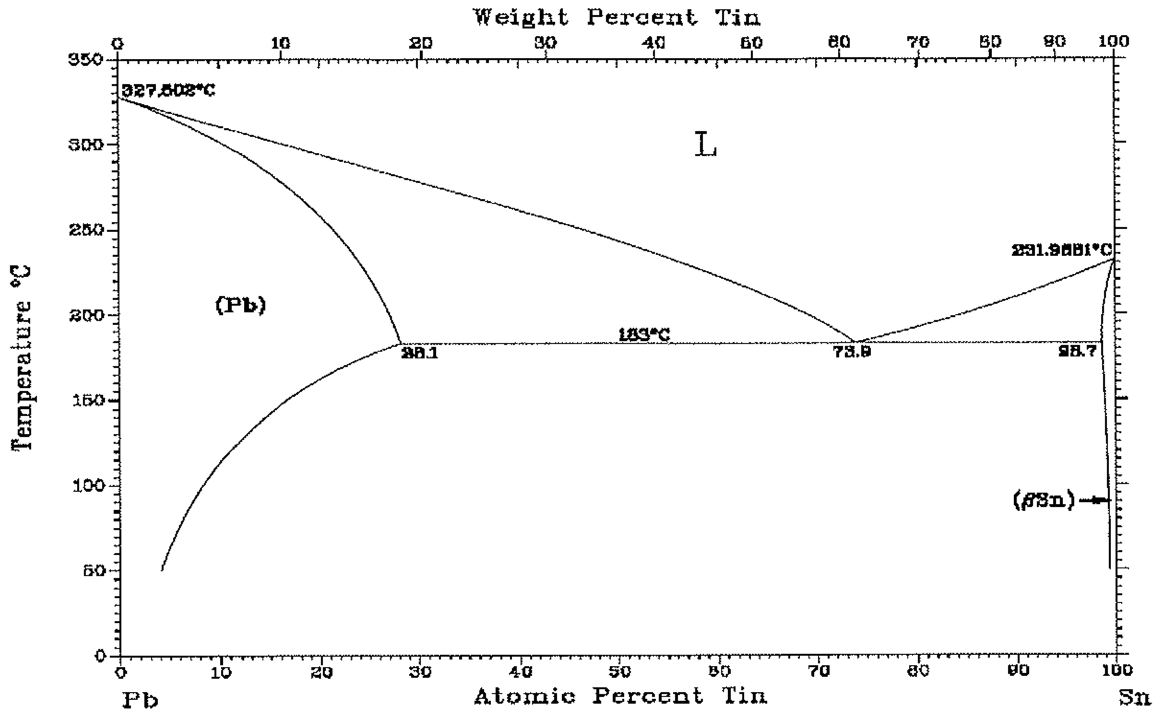

Figure 33. Lead-Tin phase diagram.

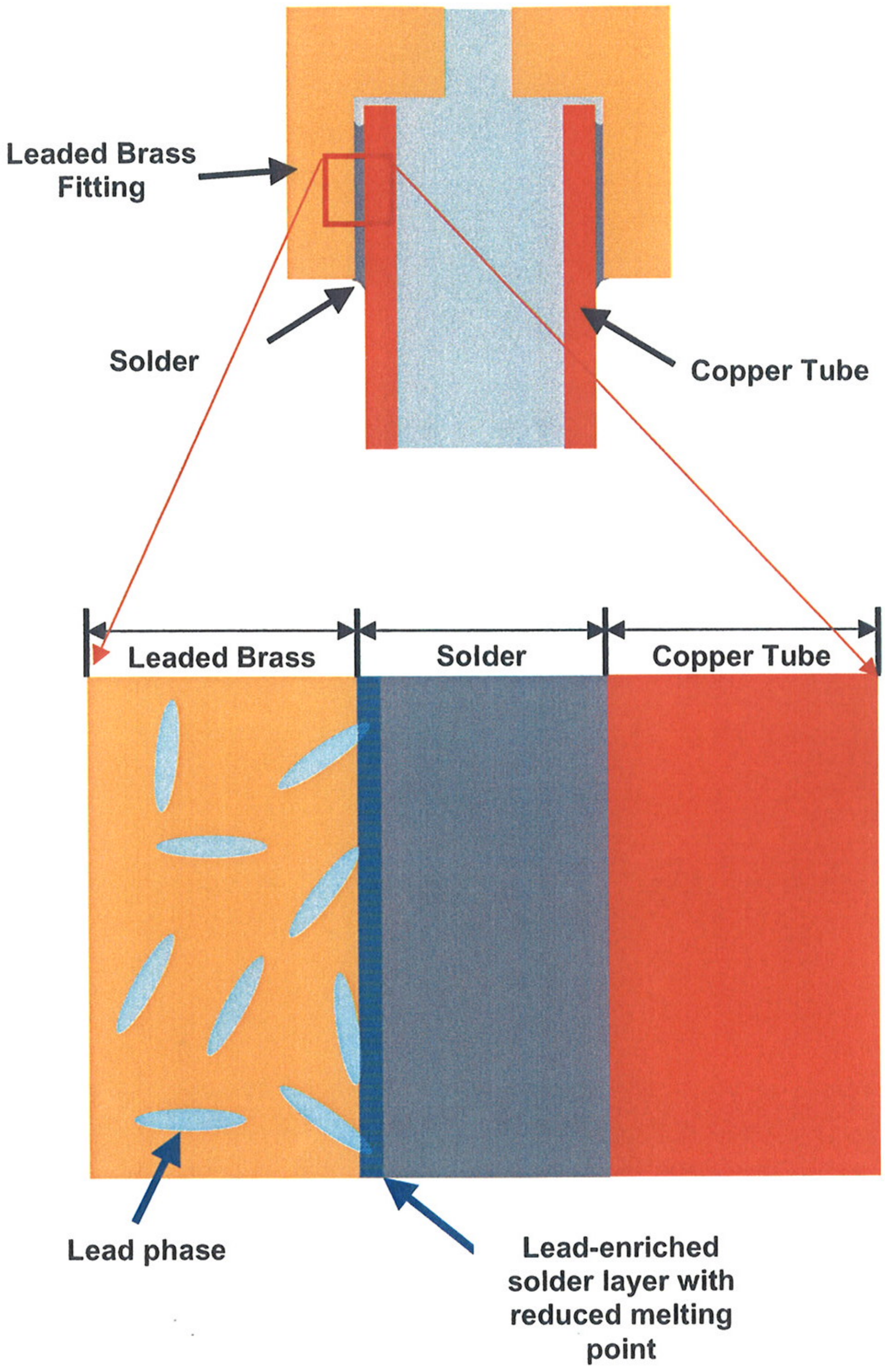

Figure 34. Schematic of a leaded brass fitting soldered to a copper tube.

Conclusions

The opinions and findings in this report were reached to a reasonable degree of scientific and engineering certainty based on information available to date. A summary of the findings and opinions reached in this report is listed below:

1. At the time the fire began, all joints of the water piping were intact.
2. The heat from the fire was sufficient to melt the solder at the copper/brass interface, but not the copper/copper soldered joints.
3. Pressure within water line provided the force necessary to separate joint between the copper tube and the brass valve when the solder melted.
4. The separation of the joint between the copper tube and the brass compression fitting followed. Either the weight of the brass valve/copper tube assembly or the movement of components during the fire could have provided sufficient force to separate this joint once the solder melted.

If additional information becomes available or additional analysis is performed, I reserve the right to revise these opinions.